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Lengthening the productive life of wells penetrating Alaska's North Slope permafrost by the optimization of annular completion fluids

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Introduction

This project addresses damage to heavy oil wells on the North Slope of Alaska due to subsidence from permafrost thaw. There is an estimated 24-33 billion barrels of heavy oil on the North Slope. Much of this oil will need thermal enhanced oil recovery techniques to be produced. If mitigations are not put in place, heat from producing oil and high heat thermal injection will increase the rate of permafrost thaw and subsidence from what is currently seen in conventional wells on the North Slope. This project uses a scaled down physical model of three different EOR completions in a frozen block of soil. The three completions modeled are: 1) a well with a brine annular fluid; 2) a well with low thermal conductivity annular fluid (insulating packer fluid); and 3) a well with vacuum insulated tubing and brine annular fluid. Data collected from thermistors in the soil and thermal images of the frozen soil block allow comparison of thaw around each well. Using the thaw data to estimate the extension of well life of each completion verse cost of each completion allows for optimization of how to best complete heavy oil wells in North Slope permafrost. Success of the project will help bring significant cost savings and life to Alaska's North Slope oil fields.

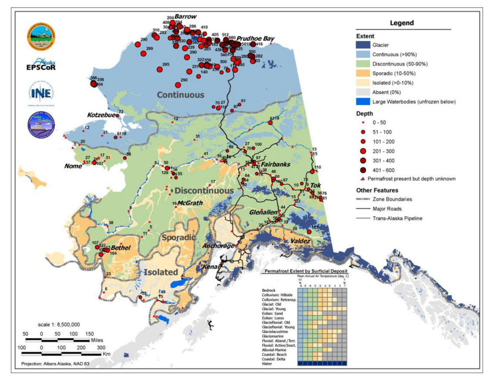

Figure 1: Generalized distribution of permafrost in Alaska

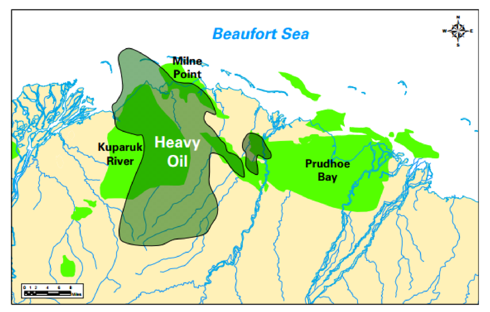

Figure 2: Heavy Oil in Alaska Source: BP Alaska

Background

Significant ground ice exists in the upper permafrost on the Alaska North Slope. Subsidence becomes an issue as the ice present with the soil changes phases. For ice-rich soils, the result is a significant loss of soil mass volume. For ice poor soils, localized subsidence may not be significant, but over a thick zone, the subsidence effects be more significant. Generally, permafrost soils at depth on the Alaska North Slope are not classified as highly thaw sensitive. However, loss of bearing capacity and post thaw consolidation can lead to differential stresses within the soil mass.

Within Alaska's North Slope oil production regions, two areas of subsidence have practical importance:

1) Subsidence resulting in thaw instability within well strings.

2) Near surface subsidence resulting from ice-rich horizons within the upper permafrost. Upper permafrost disturbance impacts surface infra-structure and well operation. This also includes supply transportation infrastructure extending into the discontinuous permafrost zones. (Bray 2014)

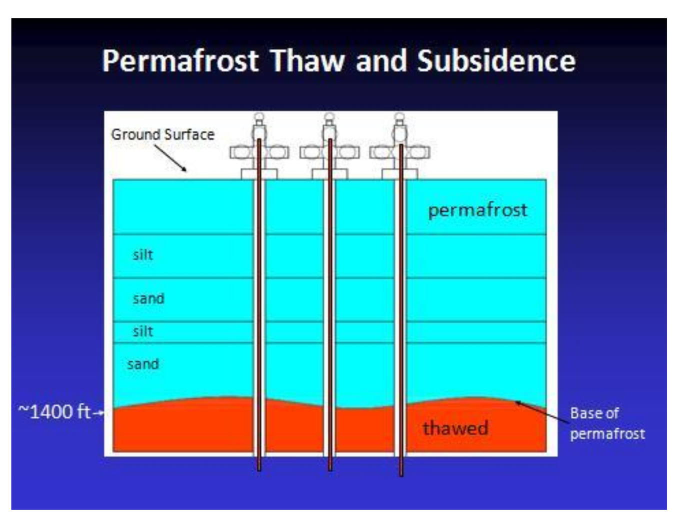

Figure 3: Well permafrost relationship (initial)

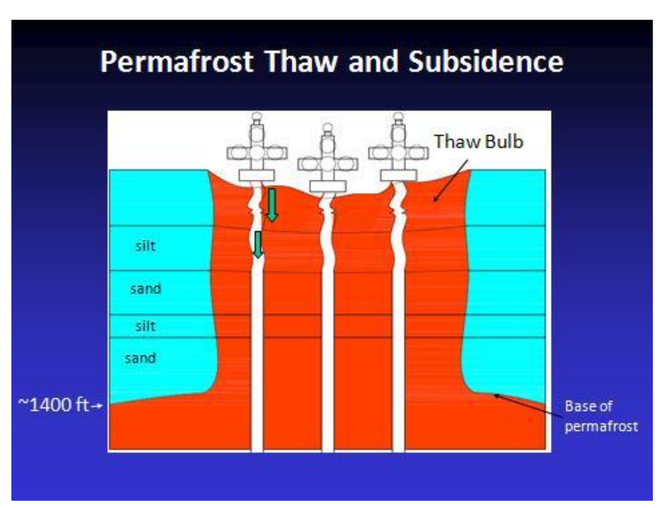

Figure 4: Thermally induced thaw of permafrost and potential subsidence and well instability. Teal colored arrows indicate downward drag forces on wells.

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Disclaimer: This poster was prepared as final deliverable for a senior capstone design project at the Petroleum Engineering Department, University of Alaska Fairbanks. The views and opinions are only those of the author.

Reference: Bray, Matthew. Institute of Northern Engineering, University of Alaska Fairbanks. 2014.

Experimental Facility

At UAF, a 1m x 1m x 2m frost heave cell is maintained inside of a climate controlled cold room. The cell is adaptable to small scale physical modeling scenarios in frozen soils.

Six model well casings and tubings were placed in the cell. Two of the model tubings are vacuum insulated (VIT). In order to mimic a joint in the VIT's there is a brass ring in the vacuum chamber that allows heat to transfer from the inside of the tubing to the outside. Inside of the model tubings is a controllable heating system consisting of heat tape, a thermistor, and dry packed sand. In the annulus three types of thermal fluids were placed, including a brine filled annulus, insulating packer fluid filled annulus, and vacuum insulated tubing with brine filled annulus.

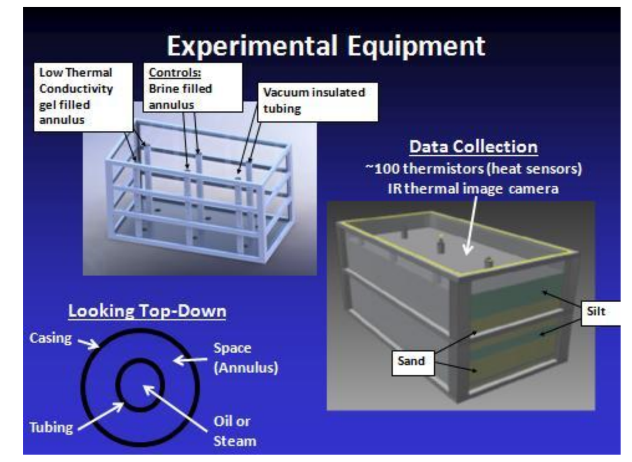

Figure 5: Schematic of experimental set-up

The cell was then filled with 4 total layers of alternating of sand and silt and then frozen. Inside of the soil are ~100 thermistors (heat sensors) on a grid pattern.

Figure 6: Frost cell with casings installed and three quarters full. Wires go to embedded thermistors and out to a Campbell CR1000 data logger.

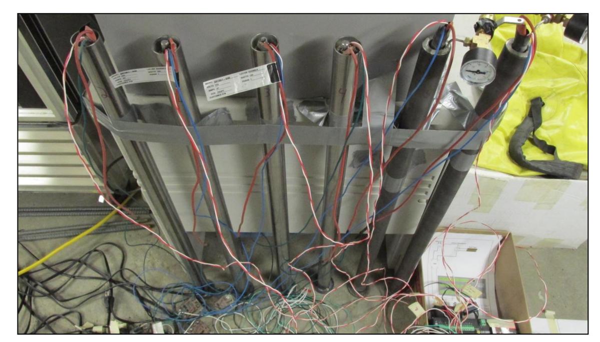

Figure 7: Model tubings with heating system. Two right hand tubes are vacuum insulated tubes with vacuum gauges to insure a vacuum.

Figure 8: Waterproof Thermistor. 120 thermistors were made.

Approach

The soil was frozen to 20 degrees Fahrenheit in order to mimic temperatures found near three hundred feet of depth in permafrost. Soil moisture contents were made as high as possible to simulate ice rich soil. Moisture contents average near 20 percent in the bottom layer, rising to near 33 percent in the top layer. Data loggers were set to log temperature in the 120 thermistors at 5 min intervals.

In order to operate at a safe lab temperature, the model wells were set to maintain a temperature of 100 degrees Fahrenheit.

Prior to placing the model tubings in the casings the heating systems were tested and analyzed in air (*Figure 9*).

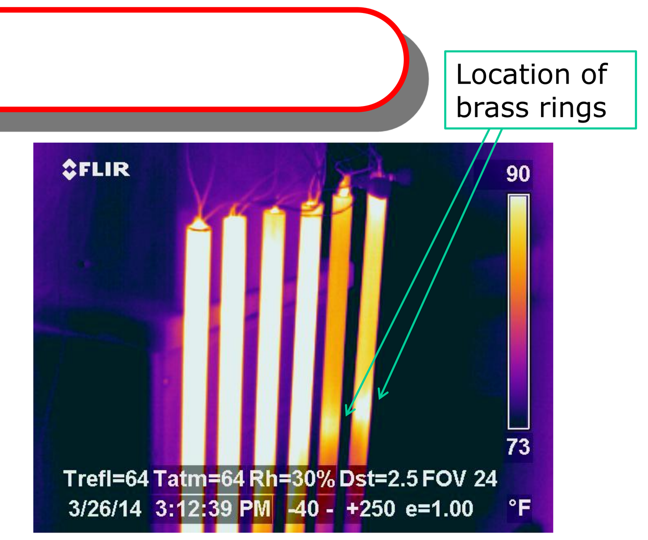

Figure 9: Testing heating systems in tubings prior to installation in casings. Notice Significantly cooler vacuum insulated tubes on right with hot areas where internal brass rings mimic joint connections.

This project produces a number of different aspects to analyze. Foremost is the differences in thermal heat transfer due to different completions. Other aspects of analysis include effects of joint connections in VIT, effect of convection currents in annular fluid, thermal conductivity of soil due to soil type (sand vs. silt), soil moisture contents, soil thickness, effect of merging thaw bulbs, and possible surface indications of subsidence within the soil.

Applicability

There are a number of factors effecting whether a well will be impacted by permafrost thaw subsidence including thermal throughput of the well, soil classification, lithology, casing specifications, well spacing, well position in well row, and well trajectory. By optimizing the annular fluid/insulation the permafrost can be protected from degradation. Stopping the degradation takes the rest of the numerous factors out of consideration and simplifies the solution to a single effective mitigation.

Key Findings / Results

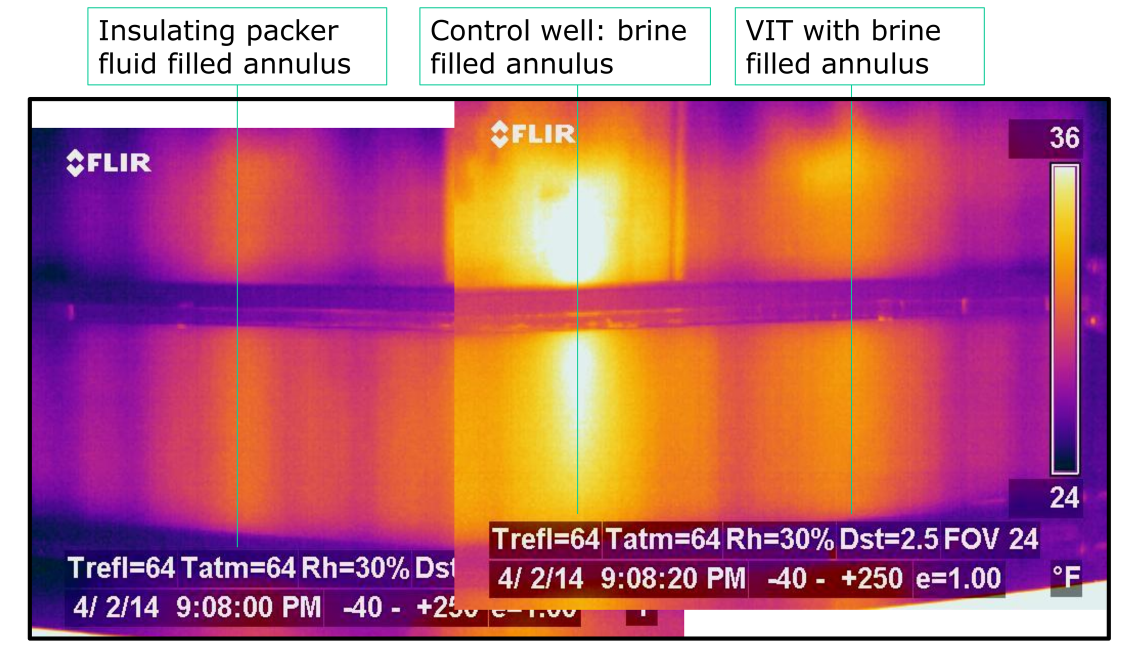

Figure 10: Thermal image of front side of cell (side with wells up at edge of cell). Centerline location of wells marked with lines.

Figure ten shows a thermal image 6 hours after heating systems were turned on. The insulating packer fluid filled wells show the least amount of heat transfer out of the well. This is remarkable when taking into consideration figure 9 shows the VIT's have the least amount of heat transfer when all wells are in air. A perfect vacuum cannot transfer heat and a near perfect vacuum, as the VIT's have, should transfer little heat. So why are the VIT's transferring more heat than the insulating packer fluid wells? Heat gets transferred out of VIT's at the joint connections where there is not a vacuum. It is reasonable to suggest convection currents in the free flowing brine are carrying heat away from the brass ring joint connection and transferring heat out of the VIT's.

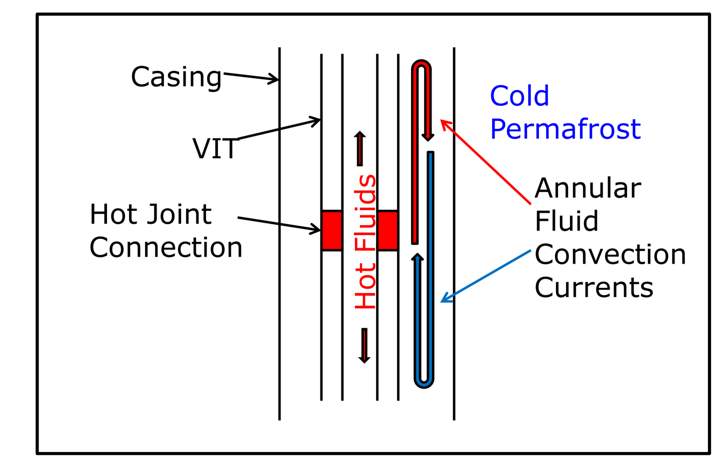

Figure 11: Schematic of annular fluid convection currents caused by VIT joint connections

Figure 12: Photo showing thawed zones. VIT's at bottom and insulating packer fluid wells at top of picture. Surface subsidence observed in control wells, located in middle of picture.

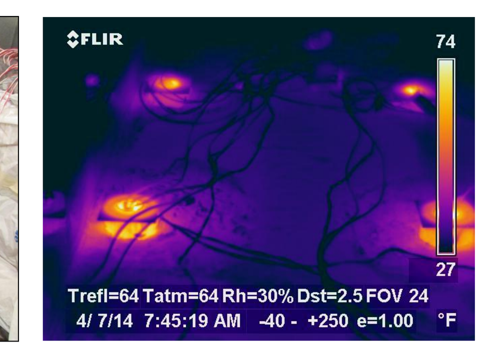

Figure 13: Thermal image of control wells (bottom) and insulating packer fluid wells (top). Minimal thaw zone around top wells. Surface subsidence observed around bottom wells.

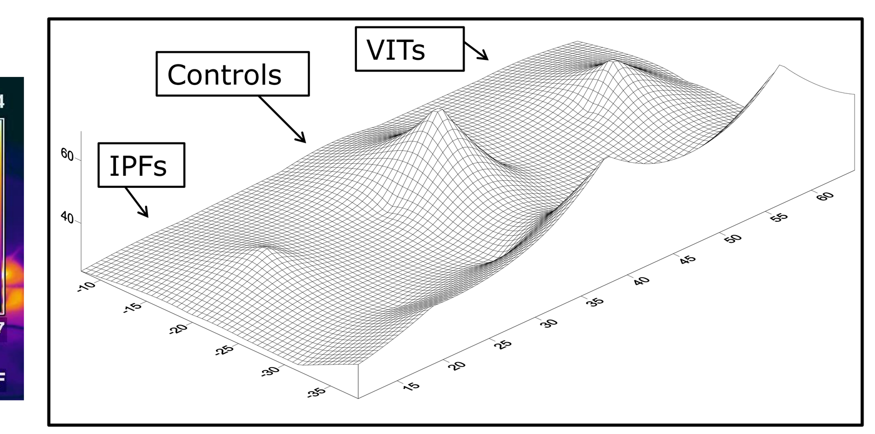

Figure 14: 3D temperature profile of top soil layer 3 days after start of heating systems. Vertical axis indicates temperature. VIT's (right), controls (middle), insulating packer fluid (left). Front VIT lost vacuum and shows higher temp than back VIT.

Conclusions

The concept of thaw instabilities within oil well strings is a complex problem with no easy solution. A significant amount of research and effort is needed to understand the physical mechanisms and behavior resulting from thaw of the permafrost soils. This understanding must account for the interaction between well strings, thawing and thawed soils, and frozen soils. (Bray, 2014)

A cost effective system of a combined insulating packer fluid in the annulus around VIT's is the best protection against permafrost degradation. The insulating packer fluid will help stop heat loss through joint connections, help stop convective currents, and in the case of a hole on the outside of the VIT, the insulating packer fluid will be pushed into the vacuum chamber of the VIT.

Further Research should include a combination of both physical and computer modeling.